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# Analysis of barriers to implement solar power installations in India using interpretive structural modeling technique

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ABSTRACT

India is fast emerging economy in Asia and world. India's manufacturing sector is growing faster and domestic demand is also increasing. India has a severe electricity shortage. It needs massive additions in capacity to meet the demand of its rapidly growing economy. To maintain the pace of economic growth with reduction in emission of greenhouse gases, India must reduce its dependency on fossil fuels for electrification. Hence the requirement of solar power installations in India has increased. In this context, this study aims to develop a structural model of the barriers to implement solar power installations in India. Thirteen relevant barriers to implement solar power installations have been identified from the literature and subsequent discussions with experts from academia and industry. Contextual relationships among these barriers have been identified and interpretive structural modeling (ISM) technique based, a structural model of barriers to implement solar power installations in India has been developed. MICMAC analysis has also been used to carry out the classification of barriers based on dependence and driving power. One barrier has been identified as top level barrier and six bottom level barriers. This paper also suggests the different ways of removal of these barriers. Better understanding of these barriers would help organizations and government bodies to prioritize and manage their resources in an effective and efficient way so that maximum number of solar power projects can be installed in India.



**Contents**



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## 1. Introduction

Solar power comes from the energy of our Sun; a yellow dwarf star located 93 million miles from the Earth. Solar energy is the basis for all life on earth! Solar energy has been harnessed as a form of light and heat since early mankind. From the beginning of life on this planet, solar energy has been a constant and vital presence in mankind's everyday life. As technology has advanced, the uses of solar have diversified, expanded and become commercialized. Advancements in solar technology sped up exponentially in the last century and the future appears promising. At the height of the Industrial Revolution, during times when the supply of fossil fuels (i.e. oil and coal) was seemingly endless, there were a few people who were concerned about the future of the nation once these non-renewable sources have finally been exhausted, but the depletion of fossil fuels reserves at a rapid rate and global environmental concerns over their use for electric power generation has increased the interest in the utilization of renewable energy sources. Sunlight is an excellent renewable energy source and the future of using solar power is very exciting. The benefits of solar power have been identified for different sectors and tabulated [13,14] in Table 1.

Conversion of solar energy into electrical energy is solar power. The Sun's energy can be converted into electricity, either directly using photovoltaic (PV) cell or indirectly using concentrated solar power (CSP). Solar energy can also be used for heating and cool buildings, power solar cars, operating communication and navigation systems, cooking food and heating water. In particular, advances in photovoltaic technologies have brought opportunities for the utilization of solar resources for electric power generation worldwide. Solar panels have no moving parts. You just mount them out in the sun, hook up the wires, and collect power, without adding fuel or replacing worn-out parts.

### 1.1. India's power sector problems

The electricity sector in India had an installed capacity of 211.766 GW as of January 2013, the world's fifth largest. The installed capacity of thermal power in India, as of January 2013, was 141,714 MW which is 66.9% of total installed capacity and current installed base of coal based thermal power is 121,610.88 MW which comes to 57.4% of total installed base [18]. India's electricity sector faces many problems. The power sector in India consumes approximately 43% of commercial primary energy and generates 40% of India's $CO_2$ emissions [28]. Some of the power sector problems of India are summarized in Table 2 [19,28].

### 1.2. Importance of solar power in Indian context

India is one of the best recipients of solar energy due to its favorable location in the solar belt (40°S–40°N) [11]. The solar energy potential in India is immense due to its convenient location near the Equator. India receives nearly 3000 h of sunshine every year, which is equivalent to 5000 trillion kWh of energy. As shown in Table 3, India can generate over 1900 billion units of solar power annually, which estimates to be enough to service the entire annual power demand even in 2030 [32]. India is bestowed with solar irradiation ranging from 4 to 7 kWh/m$^2$/day across the country, with western and southern regions having higher solar incidence. India is endowed with rich solar energy resource. India receives the highest global solar radiation on a horizontal surface. The installed capacity of grid-connected solar energy has crossed 1 GW milestone as of July, 2012, according to Dr. Farooq Abdullah, Union Minister of New and Renewable Energy (MNRE) [39].

India has more than 150 GW of renewable energy potential [9]. Developing renewable energy can help India to increase its energy security, reduce the adverse impacts on the local environment, lower its carbon intensity, contribute to more balanced regional development, and realize its aspirations for leadership in high-technology industries. India is a country that has tremendous solar energy potential. As the nation is facing an increasing demand—supply gap in energy, it is important to tap the solar potential to meet the energy needs. Developing countries like India are bigger markets and absorb more solar PV than any other developed country like USA and Japan [4]. Although the solar energy potential in India is immense and the government of India has

**Table 1**
Benefits of solar power.

| Renewable source | Environment friendly | Unlimited amount of energy | Free energy | Beneficial to economy | Ideal for remote locations | Reduced dependency |
|---|---|---|---|---|---|---|
| Solar power comes from sun which is a renewable source of energy | Solar power is beneficial to the environment and helps to reduce the levels of greenhouse gas emission that cause global warming | The sun's energy is readily available to be harnessed for energy production | Solar energy is free. We do not have to pay for it | Once solar panels have been installed, there is no cost in using the sunlight | Where there is no easy way to supply electricity by other means | Solar power will reduce the dependency on fossil fuels and give us time to encounter the problem of fast depletion of resources |

**Table 2**
Summary of India's power sector problems.

| S. no. | Component of power generation | Description of the component |
|---|---|---|
| 1. | Coal | Despite abundant reserves of coal, India is facing a severe shortage of coal to feed its power plants [24] |
| 2. | Natural gas | The giant new offshore natural gas field has delivered less fuel than projected. India faces a shortage of natural gas |
| 3. | Hydroelectric power | Hydroelectric power projects in India's mountainous north and northeast regions have been slowed down by ecological, environmental and rehabilitation controversies, coupled with public interest litigations |
| 4. | Nuclear power | India's nuclear power generation potential has been stymied by political activism since the Fukushima disaster in Japan |
| 5. | Efficiency | Ninety percent of the coal-fired generating units in India are subcritical, with a maximum thermal efficiency of 35–38%. The average thermal efficiency of these plants is below 30% due to the high ash content and low heat content of Indian coal and inefficiencies in management [28] |
| 6. | Losses | Average transmission, distribution and consumer-level losses exceeding 30% |
| 7. | Rural electrification | About 1.5 billion people in rural India have no access to electricity. Of those who do, almost all find electricity supply intermittent and unreliable [2] |
| 8. | Government policies | Governments give away such as free electricity for farmers. This has financially crippled the distribution network, and its ability to pay for power to meet the demand. This situation has been worsened by government departments of India that do not pay their bills |
| 9. | Inefficient technology | India's coal-fired, oil-fired and natural gas-fired thermal power plants are inefficient and as compared to the average emissions from coal-fired, oil-fired and natural gas-fired thermal power plants in European Union (EU-27) countries, India's thermal power plants emit 50–120% more CO2 per kWh produced [20] |
| 10. | Power deficit | The country's overall power deficit was 8.4% in 2006 which has been risen up to 11% in 2009 [9]. During the year 2011–2012, the shortage conditions prevailed in the Country both in terms of energy and peaking availability as 8.5% and 10.6% respectively [21] |
| 11. | Increasing demand | The electrical energy demand for 2016–2017 is expected to be at least 1392 tera watt hours, with a peak electric demand of 218 GW. The electrical energy demand for 2021–2022 is expected to be at least 1915 tera watt hours, with a peak electric demand of 298 GW [22]. If current average transmission and distribution average losses remain same (32%), India needs to add about 135 GW of power generation capacity, before 2017, to satisfy the projected demand after losses |

**Table 3**
Calculation of solar potential in India.

| Land area of India | 3,287,590 km$^2$ |
|---|---|
| Approximate number of sunny days | 200 |
| Unit potential of solar power from 1 m$^2$ | 4 kWh/day |
| If conversion efficiency of solar PV cells | 15% |
| Potential units of solar power from 1 km$^2$ | 120 million units per year |
| If 0.5% of land is used for solar power installations | 16,438 km$^2$ |
| Potential units of solar power from 0.5% of land | 1972 billion units per year |

set ambitious targets, there are several barriers which come across the installations of solar power in India. Hence need arises to identify barriers and their removal to implement solar installations in India. Interpretive structural modeling (ISM) technique has been used in this paper to find the contextual relationship among various barriers. ISM is a technique which is used to give fundamental understanding of complex situations where quantitative measure of variables, affecting the system is not possible. ISM technique is suitable for our research work as the various barriers to solar power installations are not measurable in quantity.

### 1.3. Organization of the paper

Relevant literature has been explored to identify barriers to implement solar power installations in India in Section 2. Step wise elaborated ISM methodology to find levels of these barriers has been discussed in Section 3. ISM based model formation of these barriers follows in Section 4. MICMAC analysis has been presented in Section 5. Solutions for eliminating barriers or making barriers less intense have been proposed in Section 6. In the last sections, the results and discussions of this research are presented, followed by limitations and scope for future research and conclusions.

## 2. Identification of barriers to solar power installations in India

With its growing electricity demand, India has initiated steps to develop its large potential for solar energy based power generation. In November 2009, the Government of India launched its Jawaharlal Nehru National Solar Mission (JNSM) under the National Action Plan on Climate Change. Under this initiative of central government, India plans to increase solar power installed capacity in three phases. In first phase (2010–2013), target is to achieve 1100 MW of installed capacity. In second phase (2013–2017), target is to achieve 10,000 MW of installed capacity and in third phase (2017–2022) target is 20,000 MW [23].

India plans utility scale solar power generation plants through solar parks with dedicated infrastructure by state governments, among others, the governments of Gujarat and Rajasthan. Gujarat and Rajasthan are the regions with maximum solar energy potential with the availability of enough barren land which increases the feasibility of solar energy systems in these regions.

The government of India has set ambitious targets to fully harness the renewable energy resources. India has established three government bodies to promote solar energy in India. The first is the Ministry of New and Renewable Energy (MNRE), which is the nodal unit for all matters relating to renewable energy. The second, India Renewable Energy Development Agency (IREDA), is a public limited company established in 1987 to promote, develop and extend financial assistance for renewable energy and energy efficiency/conservation projects. The third, Solar Energy Centre (SEC), is a dedicated unit of the MNRE and the Government for the development of solar energy technologies and promotion of its applications through product development. Besides this, the government also offers capital subsidies to semiconductor manufacturing plants in special economic zones (SEZs) and outside SEZs through semiconductor policy launched in 2007 [32]. It aims to increase the capacity to generate renewable energy by 40–55 GW

by the end of the 13th Five-Year Plan, 2022. Depending on India's demand for power and ambitious targets of government, it seeks to increase combined solar capacity from 9 MW in 2010 to 20 GW by 2022 [9].

We have identified various barriers to implement solar power installations in India from the literature reviews and expert opinions. Literature was reviewed to identify barriers to implement solar power installations in India. Although, the literature was not relevant in Indian context, we have taken the literature from some others developed/developing countries. We assumed similar situation for India also.

We conducted a workshop, in which different experts from academia and industry were invited. Four were from industry and two were from academia. Brainstorming session was conducted and 13 relevant barriers to implement solar power installations in India were identified. Barriers identified from the literature have been explained as follows.

### 2.1. High initial capital cost

Although the cost of making solar panels is decreasing each year, a high cost of solar PV technology is main barrier to the implementation of solar power installations. The market benefits of installing the current solar PV technology are much smaller than its costs [30]. We know that solar power is environment friendly and it can help to reduce the emission of greenhouse gases but still the value of reducing greenhouse gases does not come close to making the net social return on installing solar power. This high cost is mainly due to dependence of India on imports for silicon and solar wafers used for the manufacture of solar cells. Due to lack of collaborative and goal driven efforts, the research and development programmes in this sector are on a slow track [32]. The Indian PV program for research and development of photovoltaic technology and its application have led to reduction in costs, improvement in reliability and introduction of new technologies. But still the cost of PV module is needed to be further brought down in order to achieve a major expansion in the deployment levels of solar power installations in India. In order to open new markets in urban areas the prices of PV module should be brought down to US $ 2–3/W or lower [33].

### 2.2. High pay-back period

Due to high initial capital cost and less efficiency of solar PV modules, the net pay-back period of solar power installations is high. Although the costs of solar power technologies have come down in the recent past, but still, the minimum values of levelized cost of any solar technologies would be higher than the maximum values of levelized costs of conventional technologies for power generation [8]. Moreover, estimated pay-back time depends on the installation location and orientation of solar PV module. For the locations and orientations with less incident sunlight, pay-back time will be much longer [16].

### 2.3. Less efficiency

Efficiency of solar power equipments is very less. All the absorbed solar radiation by solar cells is not converted into electricity. In addition to that the absorbed solar radiation increases their temperature which further reduces their electrical efficiency. Further, the average electrical efficiency of the system depends on weather conditions and geographic position of the photovoltaic modules [29,51]. At present the typical efficiency of flat-plate crystalline Si solar cell modules is around 15%. However, flat-plate PV and concentrator III–V compound multi-junction solar cells have the potential in principle to increase the efficiency to almost 30% and more than 50%, respectively [31].

### 2.4. Need for backup or storage device

Due to weather conditions and the fact that day light hours are limited, along with an uneven geographic distribution of solar resources, solar power is intermittent [34]. To supply un-interrupted and continuous power supply, backup or storage devices are required. In addition to that, disposal of battery (storage device) is a major environmental issue [12].

### 2.5. Unavailability of solar radiation data

Unavailability of solar radiation data is also a major barrier. Solar energy incident on the earth's surface depends on the geographic location, earth–sun movement, tilts of the earth's rotational axis and atmospheric attenuation due to suspended particles. Accurate solar radiation data, required to establish solar power projects, is not available. It is suggested that India should set up its own solar radiation data collection stations for accelerating development of solar power projects in the country [5].

### 2.6. Lack of consumer awareness to technology

Consumers are not aware to solar power technology and there is a lack of promotion of it. Consumers have insufficient information about solar power technologies as the solar power technologies are relatively new. Many customers, for example, may think that solar technologies are unreliable because they are available only when the sun is shining. They are unlikely to be aware that these intermittent technologies can be highly reliable when combined with other options such as hybrid photovoltaic/thermal (PV/T) system [29]. Even local electricity companies may be unfamiliar with solar power technologies and the way it could fit into their systems. Lack of consumer knowledge and familiarity with solar power is an important barrier for solar energy to capture a significant share of the energy market in the years to come.

### 2.7. Lack of trained people and training institutes

Very less people are trained of this technology and solar training institutes are few. The scaling-up of solar power technologies is constrained by incompetent technical people and training institutional barriers. Government is providing subsidies to institutions, organizations and individuals to promote solar power installations but subsidies will not work for long if customers can only access bad products installed by incompetent technicians [10].

### 2.8. Lack of financing mechanism

Financing mechanism is not appropriate. Solar energy developers and customers have difficulty in obtaining financing at rates as low as may be available for conventional energy facilities. In addition to having higher transaction costs, financial institutions are generally unfamiliar with the new solar technologies and likely to perceive them as risky, so that they may lend money at higher rates. High financing costs are especially significant barrier of solar power installation, since solar power plants generally require higher initial investments than fossil fuel plants, even though they have lower operating costs [3,8].

### 2.9. Lack of sufficient market base

There is lack of market infrastructure and distribution network. As the solar power technology is facing numerous barriers in the competitive market, the size of green electricity market is not big enough. Due to lack of sufficient market base, private investment is discouraged. Solar power projects and companies are generally small. Thus they have fewer resources than large generation companies or integrated utilities. These small companies are less able to communicate directly with large numbers of customers. They will have less clout negotiating favorable terms with larger market players. And they are less able to participate in regulatory or legislative proceedings, or in industry forums defining new electricity market rules [43].

### 2.10. Lack of local infrastructure

Lack of infrastructure is further identified as a barrier. Additional infrastructure is required for solar power installation. Solar power plants are often located in remote areas, therefore, require the construction of additional transmission lines, which has proven to be a challenge for several reasons [34]. As per the opinion of developers, ‘Land Acquisition’ is the most important factor for infrastructure development [5]. The approval processes and inability of the state governments to provide single window clearance to developers made the infrastructure further important barrier.

### 2.11. Lack of political commitment

Lack of political commitment to take strong measures for the promotion of solar power is another barrier for solar power installations. It is possible to meet world's energy, development and environmental needs by successful adoption of solar power installations, but achieving these goals will take determined action and political will among all the governments and international institutions of the world [6]. Our neighboring country, China, is emerging as a world leader in solar power with strong political commitment.

### 2.12. Lack of adequate government policies

Policy and regulatory barriers are the most significant barriers for solar power development in India. Government policies are not adequate enough to encourage the solar power installations. As per the opinion of developers, ‘clarity in guidelines’ and ‘long-term planning’ are most important factors of policy and regulatory barriers [5]. Regulatory approvals are major barriers for the promotion of solar power installations. State and central government agencies have to play vital roles in policy

**Table 4**
Brief summary of various barriers to implement solar power installations in India as reported in literature.

| S. no. | Barriers to implement solar power installations | Description of barriers | Researcher's |
|---|---|---|---|
| 1. | High cost | Initial capital cost of solar power installation is high | [1,7–9,12,30,32,33,34,36,37,43] |
| 2. | High pay-back period | The pay-back period of invested money is high | [16,10] |
| 3. | Less efficiency | Efficiency of solar power equipments (photovoltaic panels) is less | [8,29,31] |
| 4. | Need for backup or storage device | As the sun light is not available all the times, we need backup or storage device to supply un-interrupted and continuous supply | [12,10,49] |
| 5. | Unavailability of solar radiation data | Solar energy incident on the earth's surface is not uniform everywhere. It depends on geographic location and various other atmospheric factors. Accurate solar radiation data is not available | [5,11] |
| 6. | Lack of consumer awareness to technology | Large segment of consumers do not know about solar power technology and its benefits. There is lack of promotion also | [12,32,34,35,36,37,43,48] |
| 7. | Lack of trained people and training institutes | Very less people are trained of this technology and training institutes are few | [3,7,8,10,27,35,36,50] |
| 8. | Lack of financing mechanism | Financing mechanism is not customer and investor friendly | [3,8,12,27,32] |
| 9. | Lack of sufficient market base | Due to lack of sufficient market base, private investment is discouraged | [3,7,27,37,43,48] |
| 10. | Lack of local infrastructure | Additional infrastructure is required for solar power installations | [5,34,35,37] |
| 11. | Lack of political commitment | Lack of political commitment to take strong measures for the promotion of solar power installations | [6,12,34,45] |
| 12. | Lack of adequate government policies | Government policies are not adequate enough to encourage the solar power installations | [3,5,7,9,12,15,17,27,34,35,36,43,50] |
| 13. | Lack of R&D work | Research & development work is slow | [10,32,35,37] |

**Table 5**
Structured self-intersection matrix (SSIM) for barriers to implement solar power installation in India.

| S. no. | Barrier to implement solar power | 13 | 12 | 11 | 10 | 9 | 8 | 7 | 6 | 5 | 4 | 3 | 2 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1. | High initial capital cost | A | A | O | A | A | O | O | O | O | A | O | V |
| 2. | High pay-back period | A | O | O | A | O | O | O | O | O | A | A | |
| 3. | Less efficiency | A | O | O | O | O | O | A | O | A | O | | |
| 4. | Need for backup or storage device | A | A | O | A | O | O | O | O | O | | | |
| 5. | Unavailability of solar radiation data | X | A | O | A | O | O | O | O | | | | |
| 6. | Lack of consumer awareness to technology | O | A | X | O | V | X | V | | | | | |
| 7. | Lack of trained people and training institutes | V | A | A | O | A | A | | | | | | |
| 8. | Lack of financing mechanism | O | A | A | V | X | | | | | | | |
| 9. | Lack of sufficient market base | O | A | A | X | | | | | | | | |
| 10. | Lack of local infrastructure | O | A | A | | | | | | | | | |
| 11. | Lack of political commitment | V | V | | | | | | | | | | |
| 12. | Lack of adequate government policies | V | | | | | | | | | | | |
| 13. | Lack of R&D work | | | | | | | | | | | | |

development, regulation, and promotion of solar power installations in India.

### 2.13. *Lack of research & development work*

Lack of research and development work is also a barrier to implement solar power installations in India. High cost and less efficiency of solar photovoltaic panels are due to lack of R&D work. The research and development programmes in solar technologies are on a slow track. R&D work is lacking due to lack of collaborations and goal driven efforts among national and international organizations [32]. R&D work is also lacking behind due to shortage of finance, private investment and R&D institutions. The brief summary of various barriers to implement solar power installations in India as reported in the literature has been shown in Table 4.

Again brainstorming session was conducted to reach consensuses about the contextual relationships (pair wise) to form a structural self-interaction matrix (elaborated in Section 3).

## 3. Interpretive structural modeling methodology to find the levels of barriers to solar power installations in India

First proposed by J. Warfield in 1973, interpretive structural modeling (ISM) is an effective methodology for dealing with complex issues. It enables individuals or groups to develop a map of the complex relationships between the many elements involved in a complex situation. ISM is often used to provide fundamental understanding of complex situations, as well as to put together a course of action for solving a problem [41]. It has been used worldwide by many prestigious organizations including NASA. ISM is a combination of three modeling languages viz: words, digraphs and discrete mathematics, to offer a methodology for structuring complex issues. ISM is particularly useful and interpretive as judgment of working participants in a group for the study decides whether and how the variables are related [26]. The various steps, which lead to development of an ISM, are as follow [40]:

*Step* 1: identify issues/variables to be studied. In our research work barriers to implement solar power installations in India have been identified as variables.
*Step* 2: then the contextual relationship among the variables identified in step 1, with respect to which pairs of variables are examined.
*Step* 3: to indicate pair wise relationship among variables, a structural self-interaction matrix (SSIM) is developed.
*Step* 4: from the SSIM a reachability matrix is developed. The matrix is checked for transitivity. The transitivity of the contextual relationships is a basic assumption made in ISM and it states that if variable *X* is related to variable *Y* and variable *Y* is related to variable *Z*, then variable *X* is necessarily related to variable *Z*.
*Step* 5: partitioning of levels is done of the reachability matrix obtained in Step 4.
*Step* 6: a directed graph is drawn based on the contextual relationships in the reachability matrix, and the transitive links are removed.
*Step* 7: by replacing variable nodes with statements, the diagraph is converted into an interpretive structural model.

**Table 6**
Initial reachability matrix for barriers to implement solar power installations in India.

| S. no. | Barrier to implement solar power | 1 | 2 | 3 | 5 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1. | High initial capital cost | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 2. | High pay-back period | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 3. | Less efficiency | 0 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 4. | Need for backup or storage device | 1 | 1 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 5. | Unavailability of solar radiation data | 0 | 0 | 1 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 |
| 6. | Lack of consumer awareness to technology | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 1 | 1 | 0 | 1 | 0 | 0 |
| 7. | Lack of trained people and training institutes | 0 | 0 | 1 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 1 |
| 8. | Lack of financing mechanism | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 1 | 1 | 1 | 0 | 0 | 0 |
| 9. | Lack of sufficient market base | 1 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 1 | 1 | 0 | 0 | 0 |
| 10. | Lack of local infrastructure | 1 | 1 | 0 | 1 | 1 | 0 | 0 | 0 | 1 | 1 | 0 | 0 | 0 |
| 11. | Lack of political commitment | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| 12. | Lack of adequate government policies | 1 | 0 | 0 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 1 | 1 |
| 13. | Lack of R&D work | 1 | 1 | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 |

**Table 7**
Final reachability matrix for barriers to implement solar power installations in India.

| S. no. | Barrier to implement solar power | 1 | 2 | 3 | 5 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | Driving power |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1. | High initial capital cost | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 02 |
| 2. | High pay-back period | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 01 |
| 3. | Less efficiency | 0 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 02 |
| 4. | Need for backup or storage device | 1 | 1 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 03 |
| 5. | Unavailability of solar radiation data | 1* | 1* | 1 | 1* | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 06 |
| 6. | Lack of consumer awareness to technology | 1* | 1* | 1* | 1* | 1* | 1 | 1 | 1 | 1 | 1* | 1 | 1* | 1* | 13 |
| 7. | Lack of trained people and training institutes | 1* | 1* | 1 | 1* | 1* | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 1 | 07 |
| 8. | Lack of financing mechanism | 1* | 1* | 1* | 1* | 1* | 1 | 1 | 1 | 1 | 1 | 1* | 1* | 1* | 13 |
| 9. | Lack of sufficient market base | 1 | 1* | 1* | 1* | 1* | 1* | 1 | 1 | 1 | 1 | 1* | 1* | 1* | 13 |
| 10. | Lack of local infrastructure | 1 | 1 | 1* | 1 | 1 | 1* | 1* | 1* | 1 | 1 | 1* | 1* | 1* | 13 |
| 11. | Lack of political commitment | 1* | 1* | 1* | 1* | 1* | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 13 |
| 12. | Lack of adequate government policies | 1 | 1* | 1* | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1* | 1 | 1 | 13 |
| 13. | Lack of R&D work | 1 | 1 | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 06 |
| **Dependence power** | | 11 | 13 | 10 | 10 | 9 | 6 | 7 | 6 | 6 | 6 | 6 | 6 | 9 | 105/105 |

* Used in matrix for “rule of transitivity”.

*Step* 8: the ISM model developed in Step 7 is reviewed to check for conceptual inconsistency and necessary modifications are made.

### 3.1. Data gathering and formation of structural self-interaction matrix (SSIM)

As mentioned earlier in Section 5, with the consultation of industry and the academia experts during the workshop conducted, the nature of the contextual relationships among the barriers was identified to implement solar power installations in India. Following four symbols have been used for developing SSIM to denote the direction of relationship between two barriers $i$ and $j$:

V—barrier '*i*' will lead to barrier '*j*';
A—barrier '*j*' will lead to barrier '*i*';
X—barrier '*i*' and '*j*' will lead to each other;
O—barrier '*i*' and '*j*' are unrelated.

SSIM has been developed on the basis of contextual relationships (Table 5). Barrier 1 leads to barrier 2 so symbol 'V' has been given in the cell (1,2); barrier 13 leads to barrier 3 so symbol 'A' has been given in the cell (3,13); barrier 6 and 11 lead to each other so symbol 'X' has been given in the cell (6,11); barrier 4 and 9 do not lead to each other so symbol 'O' has been given in the cell (4,9) and so on. The number of pair wise comparison question addressed for developing the SSIM is $((N)*(N-1)/2)$, where $N$ is the number of barriers.

### 3.2. Reachability matrix

The SSIM obtained from the previous section is converted into initial reachability matrix, which is a binary matrix, by substituting V, A, X, O by 1 or 0 and using following rules:

- The $(i, j)$ value in the reachability matrix will be 1 and $(j,i)$ value will be 0, if $(i, j)$ value in the SSIM is V; for V(1,2) in SSIM, '1' has been given in cell(1,2) and '0' in cell(2,1) in initial reachability matrix.
- The $(i, j)$ value in the reachability matrix will be 0 and $(j, i)$ value will be 1, if $(i, j)$ value in the SSIM is A; for A(2,4) in SSIM, '0' has been given in cell(2,4) and '1' in cell(4,2) in initial reachability matrix.
- The $(i, j)$ and $(j, i)$, both values will be 1 in the reachability matrix, if $(i, j)$ value in the SSIM is X; for X(6,11) in SSIM, '1' has been given in cell(6,11) and '1' in cell(11,6) also in initial reachability matrix.
- The $(i, j)$ and $(j,i)$, both values will be 0 in the reachability matrix, if $(i, j)$ value in the SSIM is O; for O(5,9) in SSIM, '0' has been given in cell(5,9) and '0' in cell(9,5) also in initial reachability matrix.

An initial reachability matrix for the barriers to implement solar power installations has been obtained as shown in Table 6.

By adding transitivity to initial reachability matrix as explained earlier in Step 4, the final reachability matrix has been obtained (Table 7). From the final reachability matrix, the driving power and the dependence power of each barrier have been obtained.

### 3.3. Level's partitioning

The level's partitioning is done to get the importance level of each barrier. From the final reachability matrix, the reachability and antecedent set [52,53] for each barrier have been obtained. The reachability set of a barrier is the set of barriers influenced by it and the barrier itself, whereas the antecedent set of a barrier is the set of barriers which may influence it and the barrier itself. Reachability set, antecedent set and intersection sets for all the barriers have been found. In the ISM hierarchy, the barrier having same reachability and intersection has been assigned as level 1 barrier-top level (Table 8).

Level 1 is then discarded for the next iteration to find further levels. Second iteration for partitioning of levels of barriers to implement solar power installations in India has been shown in Table 9.

This iterative procedure is repeated till the level of each barrier is found. These levels have been summarized in Table 10.

**Table 9**
Second iteration for partitioning of levels of barriers to implement solar power installations in India.

| Barrier s. no. | Reachability set | Antecedent set | Intersection | Level |
|---|---|---|---|---|
| 1. | 1 | 1,4,5,6,7,8,9,10,11,12,13 | 1 | 2nd |
| 2. | | | | 1st |
| 3. | 3 | 3,5,6,7,8,9,10,11,12,13 | 3 | 2nd |
| 4. | 1,4 | 4,5,6,7,8,9,10,11,12,13 | 4 | |
| 5. | 1,3,4,5,13 | 5,6,7,8,9,10,11,12,13 | 5,13 | |
| 6. | 1,3,4,5,6,7,8,9,10,11,12,13 | 6,8,9,10,11,12 | 6,8,9,10,11,12 | |
| 7. | 1,3,4,5,7,13 | 6,7,8,9,10,11,12 | 7 | |
| 8. | 1,3,4,5,6,7,8,9,10,11,12,13 | 6,8,9,10,11,12 | 6,8,9,10,11,12 | |
| 9. | 1,3,4,5,6,7,8,9,10,11,12,13 | 6,8,9,10,11,12 | 6,8,9,10,11,12 | |
| 10. | 1,3,4,5,6,7,8,9,10,11,12,13 | 6,8,9,10,11,12 | 6,8,9,10,11,12 | |
| 11. | 1,3,4,5,6,7,8,9,10,11,12,13 | 6,8,9,10,11,12 | 6,8,9,10,11,12 | |
| 12. | 1,3,4,5,6,7,8,9,10,11,12,13 | 6,8,9,10,11,12 | 6,8,9,10,11,12 | |
| 13. | 1,3,4,5,13 | 5,6,7,8,9,10,11,12,13 | 5,13 | |

**Table 8**
First iteration for partitioning of levels of barriers to implement solar power installations in India.

| Barrier s. no. | Reachability set | Antecedent set | Intersection | Level |
|---|---|---|---|---|
| 1. | 1,2 | 1,4,5,6,7,8,9,10,11,12,13 | 1 | |
| 2. | 2 | 1,2,3,4,5,6,7,8,9,10,11,12,13 | 2 | 1st |
| 3. | 2,3 | 3,5,6,7,8,9,10,11,12,13 | 3 | |
| 4. | 1,2,4 | 4,5,6,7,8,9,10,11,12,13 | 4 | |
| 5. | 1,2,3,4,5,13 | 5,6,7,8,9,10,11,12,13 | 5,13 | |
| 6. | 1,2,3,4,5,6,7,8,9,10,11,12,13 | 6,8,9,10,11,12 | 6,8,9,10,11,12 | |
| 7. | 1,2,3,4,5,7,13 | 6,7,8,9,10,11,12 | 7 | |
| 8. | 1,2,3,4,5,6,7,8,9,10,11,12,13 | 6,8,9,10,11,12 | 6,8,9,10,11,12 | |
| 9. | 1,2,3,4,5,6,7,8,9,10,11,12,13 | 6,8,9,10,11,12 | 6,8,9,10,11,12 | |
| 10. | 1,2,3,4,5,6,7,8,9,10,11,12,13 | 6,8,9,10,11,12 | 6,8,9,10,11,12 | |
| 11. | 1,2,3,4,5,6,7,8,9,10,11,12,13 | 6,8,9,10,11,12 | 6,8,9,10,11,12 | |
| 12. | 1,2,3,4,5,6,7,8,9,10,11,12,13 | 6,8,9,10,11,12 | 6,8,9,10,11,12 | |
| 13. | 1,2,3,4,5,13 | 5,6,7,8,9,10,11,12,13 | 5,13 | |

We have identified six levels in our study. High pay-back period has been identified as top level barrier and lack of consumer awareness to technology, lack of financing mechanism, lack of sufficient market base, lack of local infrastructure, lack of political commitment and lack of adequate government policies have been identified as most important bottom level barriers.

## 4. ISM based model formation for barriers to solar power installations in India

Once all levels are found, these levels have been summarized in Table 10. From the final reachability matrix (Table 7), the structural model is generated by vertices and edges [42]. Out of 13 barriers, six are lying at the bottom level and one is lying at top level of ISM model. 'Lack of consumer awareness', 'lack of financing mechanism', 'lack of sufficient market base', 'lack of local infrastructure', 'lack of political commitment' and 'lack of adequate government policies' have lying at the bottom level of model. 'High pay-back period' has lying at the top level of model. Rest six barriers i.e. 'lack of trained people and training institutes', 'unavailability of solar radiation data', 'lack of R&D work', 'need for backup or storage device', 'high initial capital cost' and 'less efficiency' are lying in between top and bottom levels. Further MICMAC analysis has been carried out for classifying these 13 enablers.

This graph is called digraph. After removing the transitivity's as described in the ISM methodology, ISM model has been made as shown in Fig. 1.

**Table 10**
Various levels of barriers to implement solar power installations in India.

| S. no. | Level no. | Barrier to implement solar power installation |
|---|---|---|
| 1. | 1st | • High pay-back period |
| 2. | 2nd | • High initial capital cost<br>• Less efficiency |
| 3. | 3rd | • Need for backup or storage device |
| 4. | 4th | • Unavailability of solar radiation data<br>• Lack of R&D work |
| 5. | 5th | • Lack of trained people and training institutes |
| 6. | 6th | • Lack of consumer awareness to technology<br>• Lack of financing mechanism<br>• Lack of sufficient market base<br>• Lack of local infrastructure<br>• Lack of political commitment<br>• Lack of adequate govt. policies |

## 5. Barrier classification: MICMAC analysis

Matrice d'Impacts croises-multipication applique´ an classment (cross-impact matrix multiplication applied to classification) is abbreviated as MICMAC [41]. Classification of barriers has been carried out based on dependence and driving power with the help of MICMAC analysis. Based on their drive power and dependence power, the barriers have been classified into four categories i.e. autonomous barriers, linkage barriers, dependent and independent barriers [25,38]. The main aim of this section is to analyze the driving power and the dependency power of barriers to implement solar power installations in India. Higher dependence values for a barrier means a large number of barriers to be removed for its removal and high driving value of a barrier means a large number of barriers can be removed by removing it. The graph between dependence power and driving power for the barriers to implement solar power installations in India is given in Fig. 2.

From MIC MAC analysis, barriers have been classified into four categories explained as follows:

*Autonomous barriers*: these barriers have weak drive power and weak dependence power. They are relatively disconnected from the system, with which they have few links, which may be very strong. In our study, no barrier lies in this range.

*Linkage barriers*: these barriers have strong drive power as well as strong dependence power. These barriers are unstable in the fact that any action on these barriers will have an effect on others and also a feedback effect on themselves. In our study,

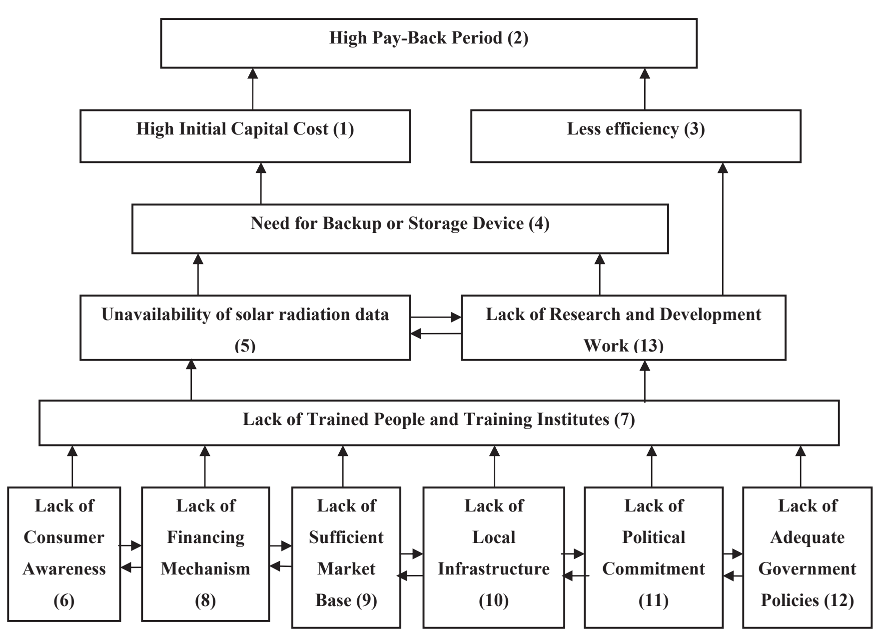


**Fig. 1.** ISM based model for barriers to implement solar power installations in India.

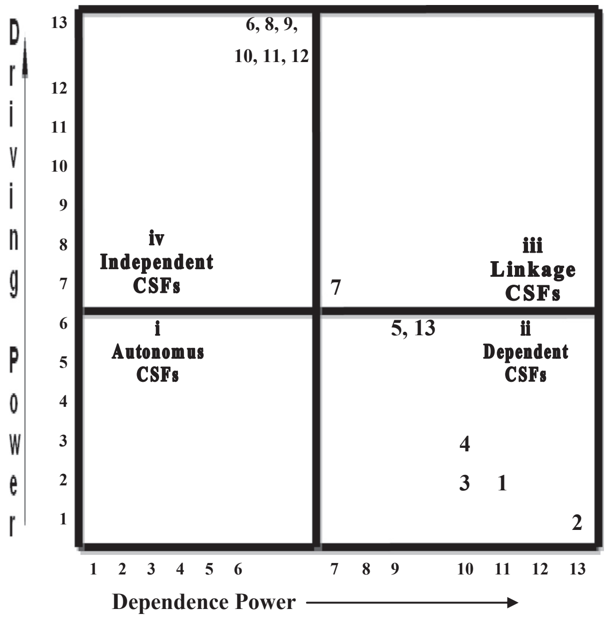


**Fig. 2.** MICMAC analysis for barriers to implement solar power installations in India.

one barrier named lack of trained people and training institutes (7) is lying in this range.

*Dependent barriers*: these barriers have weak drive power but strong dependence power. In our study, six barriers named high initial capital cost, high pay-back period, less efficiency, need for backup or storage device, unavailability of solar radiation data and lack of R&D work (1, 2, 3, 4, 5, and 13) are lying in this range.

*Independent barriers*: these barriers have strong drive power but weak dependence power. A barrier with a very strong drive power, called the 'key factor', falls into the category of independent or driver barriers. In our study, six barriers named lack of consumer awareness to technology, lack of financing mechanism, lack of sufficient market base, lack of local infrastructure, lack of political commitment and lack of adequate govt. policies (6, 8, 9, 10, 11, and 12) are lying in this range.

## 6. Proposed solution for eliminating barriers or making barriers less intense

Solar power can play a significant role in a secure and diversified energy future. Over the past several years, India has swiftly developed its solar power sector. But still achieving the target of Jawaharlal Nehru National Solar Mission (JNNSM) is a challenge for concerned government agencies. Stronger government policies are required to overcome the barriers to solar technology in India. Following are some proposed solutions for eliminating barriers or making them less intense:

(i) *At international level*: India's progress under the JNNSM, a program designed to reach 20 GW installed capacity by 2022, could falter because of the current international trade war in the solar market. India is compelled to import low cost solar panels as per WTO rules rather than developing at domestic level where solar industries cannot yet match the low prices offered by countries such as China. India should address at international level the importance of the implementation of entry-barriers, such as domestic content requirements (DCR) and anti-dumping probes, for the growth of solar industry in the country.

(ii) *Quick installations*: in order to increase the investment into solar power installations in India, there is a need for clear and consistent alignment of strong political commitment and adequate government policies that enable investors to meet their risk/return requirements and give them certainty over the time frame for their investment. Construction lead times for solar installations should be minimum. Quick installations enable a more accurate response to load growth, minimize the financial risk and better exploit rapid learning [45].

(iii) *Subsidy programmes*: subsidies to conventional fuel sources (such as coal, kerosene, diesel and LPG) should be lowered or cut down completely. These subsidies cause the price distortions and disadvantages for solar power installations. The initial phase of solar energy growth in India has been based on capital subsidy and grants. In order to maintain the growth of solar power installations there is a need to move from capital subsidy to performance based support.

(iv) *Single window clearance*: single window clearance for solar power project is one of the most courageous issues among the developers. Land acquisition is the most important factor of infrastructure barrier [49]. The process of land acquisition should be fast enough, according to technology and friendly to developers. Guaranteed availability of transmission line must be provided to developers by the utilities. It would encourage the developers and also competition among developers would provide a base to sufficient market to warrant private investment.

(v) *Solar energy parks*: solar energy parks should be developed on the patterns of technology parks and special economic zones, which would be a good example of private–public partnerships that allow aggregation of projects, create economies of scale, and enable the formation of supporting supply chains. Solar energy parks would accelerate development of resources and address multiple issues comprehensively [9].

(vi) *Tariff rates and metering system*: a possible solution for grid-connected solar power is by the provision of preferential feed-in tariffs, based on the cost of generation which may accelerate the investment in solar power installations by offering long-term contracts to renewable energy producers [46]. Two way metering or net metering systems of electrical energy must be promoted in India. Net metering is the system where households and commercial establishments are allowed to sell excess electricity they generate from their solar systems to the grid. In the night time when their solar system is not producing electricity, they can buy from grid. This would get rid from storing the solar power for night time and also cut down the electric bill of a consumer. If we are not required to store the solar power, it would save the cost of storage device and also the environment as disposal of battery is a big environmental issue.

(vii) *Consumer awareness campaign*: even though the technology has been around for a few decades, only a small fraction of the population have first-hand experience with the technology, which raises questions regarding credibility, stability and reliability of solar PV systems [34]. Government should take initiatives to make the customers aware about green solar technologies and its benefits. Among the consumers, solar power technology is perceived to be of discomfort rather than more reliable and environment friendly as compared to conventional technologies. In addition, solar power technology seems to have a greater risk, or perception of risk, than other forms of investment [43]. Higher involvement of user is necessary for the new solar power projects. Consumers are not fully aware of ongoing subsidy

and financing programs run by the governments. Efforts should be made to make customers aware of financing mechanism. To encourage rapid widespread of solar technology adoption, the media play an important role. Mass media should have special segment to focus more on solar technologies. For spreading awareness and understanding of PV technology among consumers, educational programmes should be introduced not only at universities and college level, but also primary and secondary school level [47].

(viii) *Training institutes*: solar power installations in India are badly affected due to lack of technically trained people and training institutes. More and more training institutes for solar technology should opened by government. In addition to producing technically trained people, these institutions would spread awareness and new job prospects.

(ix) *R&D programmes*: research and development programmes for solar technology play important role in designing government policies which is essential to achieve a high level of solar power installations in India. A lot more work has to be done in R&D of solar technology to increase the efficiency, bring down the cost and make it reliable to customer satisfaction [46]. Low cost of solar power projects can reduce the pay-back period and more customers can attract towards it. More research and development centers should be opened up with more incentives given to manufacturing units. To achieve the full market potential for PV, the development of high performance flat-plate PV and concentrator PV modules is necessary. Strong, targeted and globally joint research and development programmers should be started if the potential of solar energy is to be fully exploited. Government should provide sufficient funds for research and development work at the institution/university level.

(x) *Integration of solar technology with existing technology*: to compensate with the less efficiency of solar PV modules, hybrid photovoltaic/thermal (PV/T) systems should be installed. They are consisting of PV module coupled with heat extraction device which can provide electricity and thermal energy simultaneously. Integration of solar thermal power plants with existing industries which has cogeneration units and integration of solar thermal power generation unit with existing coal thermal power plants should be done [49].

(xi) *Availability of solar radiation data*: the intermittency of solar energy can be predicted, managed, and mitigated if solar radiation data are available [45]. For a new solar power project, to find the plant size (number of panels required, land requirement, etc.), capacity factor and plant costs, detailed solar radiation data and weather condition assessments are necessary. The Government of India needs to establish its own radiation data monitoring and collecting stations and provide data to developers so that financing becomes easier [5]. State and central governments should have coordination between them for sharing solar radiation data and other related information.

Finally, in order to overcome the barriers that solar power installations faces, new technological advancements followed by adequate government policies and strong political commitment must be made in order to reduce cost and consumer concerns must be dealt with through education and awareness. Efforts must be focused on the integration of solar power projects with social development projects.

## 7. Discussions

Indian economy is growing at rapid rate and the situation of energy shortage is a hurdle in the way of progress. The only solution to this problem is to harness the renewable sources of energy to their maximum potential and make them usable as the conventional reserves of energy are at the verge of depletion [40]. The enormous potential of solar energy can meet the world energy demand many times [44]. Photovoltaic are reliable source of power during extreme peak-loads. Because solar generators tend to produce the greatest amount of energy at the times consumer demand is highest, solar has an amazingly high 'effective load carrying capability' relative to other technologies [45]. It can enhance diversity in energy supply markets, contribute to long-term sustainable energy supplies, and reduce local and global atmospheric emissions. Solar energy can also provide commercially attractive options to meet specific needs for energy services, particularly in rural India and create new employment opportunities [43]. However, to achieve this goal, a number of barriers will have to be overcome to implement solar power installations in India. Policy makers therefore face lots of challenges in identifying these barriers [40] and then working upon them to improve the solar power installations in India. Some barriers have been identified in this paper and interrelationships among these barriers have been formulated using ISM methodology.

## 8. Conclusions

In this research study, an attempt has been made to identify and analyze the major barriers to implement solar power installations in India using the ISM model and MICMAC analysis. Thirteen barriers to implement solar power installations in India have been identified and interpretive structural modeling (ISM) methodology has been used for finding contextual relationships among them. Lack of consumer awareness to technology, lack of financing mechanism, lack of sufficient market base, lack of local infrastructure, lack of political commitment and lack of adequate government policies are coming at the bottom of the structural model and high pay-back period is coming at top of the structural model. The barriers which are coming at the bottom level of ISM model are also driver barriers or independent barriers. It means that they are most powerful barriers and removal of these barriers will remove maximum number of other barriers. There is no autonomous barrier in ISM model. Lack of trained people and training institutes has been identified as linkage barrier which is an unstable barrier. Any action done on this barrier will influence the other barriers and itself also. High initial capital cost, high pay-back period, less efficiency, need for backup or storage device, unavailability of solar radiation data and lack of R&D work have been identified as dependent variables. Removal of these barriers more depends on the removal of other barriers.

### 8.1. Limitations of the study

We have developed a hypothetical model of barriers to implement solar power installations in India, based on experts' opinions. The model may be tested in real world conditions to check that the barriers are complete and their relationship exists as in the literature. The results of model may vary in real world conditions. The barriers may be incomplete or their relationships may be different from the derived model. Although, the ISM based model provides a very useful understanding of the relationships among the barriers but it does not provide quantification of the influence of each barrier to implement solar power installations in India.

### 8.2. Scope of future research

In the present paper, 13 barriers are identified but in future, more number of barriers may emerge. In that case, mathematical

calculations may become difficult and tedious. Related software may be used to deal with large number of barriers. In future research, graph theory may be used for finding a quantitative measure of these barriers. Some barriers may be included or deleted to develop another model using ISM methodology for other industry in India or any other country. Further, analytical hierarchy process (AHP) and analytical network process (ANP) techniques may also be used to determine the strength of relationships among the barriers considered in our study. Interpretive ranking process (IRP) may be used to rank barriers (w.r.t. performance measures) to implement solar power installations in India. Interactive management (IM) and structural equation modeling (SEM) may be used to test the validity of the suggested model.

### 8.3. Implications of the research

This model suggests how these barriers to implement solar power installations in India are interrelated. ISM modeling provides an understanding as to how the various barriers interact with each other. This is important because of the fact that generally policy maker focuses on one or two barriers that it thinks are significant without considering the effect of other barriers. Each policy reduces one or more key barriers that impede development of solar energy but at the same time it may heighten the other barriers to solar energy rather than reduce them [7]. The ISM based model developed in this paper would enable policy makers in Indian solar energy organizations to understand different barriers to implement solar power installations in India. Decision makers must be aware of the relative importance of the various barriers and the techniques for implementing solar power installations. Although the model is developed on the basis of opinion of experts, barriers identified are quite similar and may be applied to other renewable sources of energy like wind energy with marginal modifications. This paper will surely help to prepare well for implementation of solar power installations in India more effectively and efficiently. The results of this study may help in strategic and tactical decisions making for policy makers and other organizations. Barriers with higher driving power are more of strategic orientation, while on the other hand, the barriers categorized as dependent are more towards performance and result orientation. Thus, superior results can be achieved by continuously improving the independent barriers.

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